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A CONTRIBUTION OF GENETICS TO THE PRACTICAL BREEDING OF DAIRY CATTLE

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When the writer began his work at the Maine Agricultural Experiment Station some 13 years ago the only genetic concept which played any part in or influenced the actual operations of the animal breeder was that of phaenotypic selection. The slogan and the practice, so far as there was any intelligent practice, was to "breed from the best to get the best." This was perhaps theoretically a sound enough doctrine, but there was lacking one essential to its practical operation with the anticipated degree of success. This lack, as the rapidly advancing knowledge in the field of genetics soon clearly showed, was of any precise criterion as to how the best *genotypes* were to be selected, when the breeder operated on the basis only of a knowledge of *somatic* performance or characters alone. As a matter of fact it was easy to show, as the writer did show, in the case of egg production in fowls,[1] and milk production in cattle,[2] that the phaenotypic performance was an exceedingly unreliable guide to real breeding worth.

The real value of the measure of an animal as a breeder—as a factor in the improvement of a herd or flock—is the kind of progeny which it produces. Confining the discussion to performance in respect of milk or butter-fat production, a cow may have herself a perfectly enormous record of performance but she is worthless as a *breeder* if her progeny are uniformly poor producers, which can in fact be easily shown to be often the case. Again a bull may come from ancestry of the highest performing ability in respect of milk and fat production, and consequently he may as a calf command a price in five figures, but such ancestry has repeatedly been shown to be no guarantee in fact that his progeny will be great performers.

The paramount importance of having a bull of such genotypic constitution as to insure relatively high dairy production in his offspring, if one is to attain success in the breeding of dairy cattle, is obvious. Nearly 10 years ago the writer began the intensive study of the practical problem of scientifically measuring the breeding worth or value of bulls of the dairy breeds, to the end that the farmer and breeder might operate more intelligently and successfully. It appeared evident that the most important thing which a breeder of dairy cattle desires to know is whether the animals which he breeds are transmitting productive qualities to their offspring. This information is particularly desired for the herd bull since his offspring are much more numerous than those of any single cow and he constitutes one-half the heritage given to them. It would appear beyond question that if a bull's daughters are on the average poorer milkers, or poorer in the quality of their milk, than the dams from which they came, then the bull is exercising a harmful effect upon the breed. On the other hand, if a bull's daughters are on the average measurably better than the dams from which they came, in productive qualities, then that bull is exercising a beneficial effect on the breed. Stated specifically, if D_d represents the milk production of a daughter of a given bull, and D_m the milk production of the dam of this daughter, then the measure of this bull's transmitting qualities for milk production in respect of this pair would be:

$$\textit{Sire's transmitting power} = D_d - D_m.$$

If the daughter's production is more than the dam's the sign will be plus. Insofar as one daughter-dam pair is indicative the bull is increasing the production of his daughters and consequently improving the breed. If the daughter's production is less than her dam's the sign will be minus. The bull is consequently insofar detrimental to the breed. By the summation of these plus and minus differences with regard to sign, the amount and sign of this summed quantity gives the measure of what he did for all his daughters, and dividing by the number of daughter-dam pairs gives a measure of the mean or average effect of this sire on the breed.

Being convinced that this reasoning was sound, and that if carried out thoroughly the consequences would be bound in the long run to be of incalculable, but great, practical economic value to mankind, the writer inaugurated in his laboratory at the Maine Experiment Station the project of determining the transmitting power as above defined, of every bull in the Jersey breed recorded up to 1916 as having two or more daughters whose milk-producing qualities were known, as well as the producing abilities of the dam. This project involved a very large amount of labor and was interrupted by the war, but has now been finished and will shortly be published.[3] It is the purpose of the present paper to give a brief account of the scope of the work and some of its chief results.

A prerequisite to the comparison of daughter and dam production was an accurate method of correction for change of milk and fat production with age. Considerable study has been given this problem. I showed in 1914[4] that the equation relating milk flow to age in dairy cattle was of the form

$$y = a + bx + cx^2 + d \log x.$$

Since that time these curves have been worked out in my laboratory for all the principle dairy breeds, chiefly by Miner, Gowen, Patterson, and myself. The curve for annual milk production in the Jersey breed is

$$y = 4586.50 + 307.55x - 12.65x^2 + 2216.62 \log x$$

where y denotes milk production in one year in pounds, and x denotes age in years. How closely this equation agrees with the observed facts is shown in figure 1.

It is obviously impossible to present here anything like the total results of this extensive piece of work. As a sample of the sort of results obtained table 1 is shown. This gives the net average change in butter fat production of daughters as compared with dams. The first column of table 1 gives the place occupied by the bull in the series of bulls. The second column gives the name of the bull. The third column states how many pairs of daughter-dam tests the bull under discussion had. The fourth column gives the number of pounds of butter-fat that the bull's daughters are in excess or defect of their dams. It is by this column that the bulls are arranged, the bull whose daughters produced the most butter-fat over the butter-fat production of their dams coming at the top of the list. The plus sign shows the daughters produced more butter-fat than their dams, the minus sign that they produced less butter-fat.

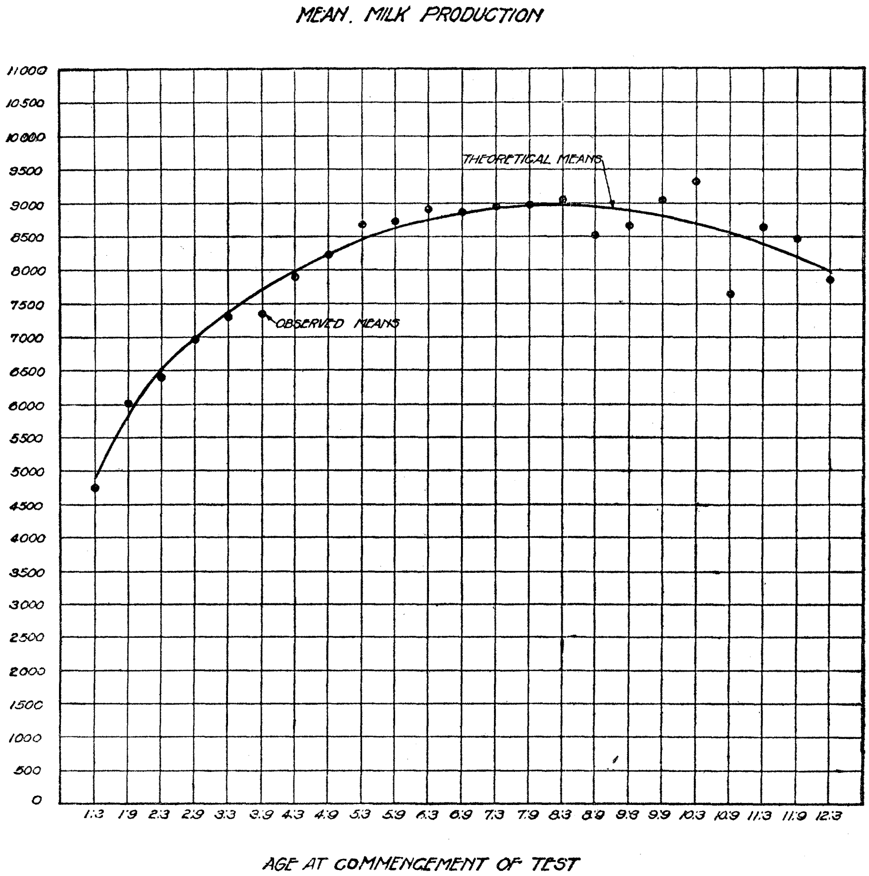

FIG. 1. Observational and theoretical curves of mean milk production (365 day) at various ages in Jersey cows.

TABLE I

BULLS IN ORDER OF CHANGE IN NET FAT OF DAUGHTERS

NO.	NAME OF BULLS	NO. OF PAIRS	NET CHANGE LBS.
1	Sans Aloi	2	+210.56
2	Signal's Successor	3	+177.72
3	Golden Glow's Chief	4	+161.93
4	Hood Farm Pogis 34th	2	+159.24
5	Tormentor's Landseer Signal	4	+153.55
6	Clear Brook Chief	2	+153.31
7	Channel King	2	+150.30
8	Golden Nero	2	+149.77
9	Majestic Fern	3	+143.97
10	Roma's Rioter of St. L.	3	+143.79
11	You'll Do Oxford	2	+136.61
12	Hood Farm Figgis Torono	3	+132.50
13	Themisia's Interested Prince	2	+131.12
14	Rinda Lad of S. B.	2	+126.38
15	The Plymouth Lad	4	+123.55
16	Hood Farm Torono	34	+121.51
17	Agatha's Brookhill Fox	2	+115.40
18	Fontaine's King	2	+111.60
19	Golden Fern's Son	9	+109.32
20	Baronetti's Golden Lad	2	+100.14
21	Spermfield Owl	26	+97.71
22	Sultan of Oaklands	3	+95.06
23	Melia Ann's King 9th	2	+93.48
24	Chenille's Golden Prince	2	+93.06
25	Eurybia's Blue Boy	3	+90.17
26	Forfarshire's King Dalton	7	+88.00
27	Rioter's Jersey Lad	7	+87.10
28	Queen's Raleigh	3	+82.68
29	Pogis 99th of Hood Farm	14	+82.34
30	Royal Majesty	5	+81.34
31	Jenny's Redfern	2	+79.56
32	Rearguard	3	+79.24
33	Oxford's Fairy Boy	2	+77.14
34	Gertie's Stoke Pogis	3	+70.59
35	Mabel's Raleigh	3	+70.51
36	Pogis 66th of Hood Farm	3	+66.86
37	My Jubilee	2	+66.75
38	Oxford Lass's Cream King	3	+66.23
39	Great Edison	2	+62.78
40	The Warden's Sir Prince	2	+60.87
41	Nova Boy of Turner	2	+58.82
42	Nebraska Lad	2	+57.14
43	Hood Farm Golden Lad	5	+56.50
44	Spermfield Owl 2d	2	+51.85
45	Marston's Interested Prince	9	+51.82
46	Eminent's Tormentor	2	+51.81
47	Chief Engineer	6	+50.20
48	Hood Farm Pogis 9th	39	+47.49
49	The Owl's Double Grandson	5	+47.45
50	Atwell Farm Melia Ann's King	2	+45.84
51	Dorinda Carling's Diploma	6	+41.77
52	Golden Shylock	5	+41.00
53	Loretta D's Champion Son	5	+38.66
54	Taurus Perfection	2	+38.56
55	Brown Bessie's Columbus	3	+38.18
56	Blue Belle's Gold Fern	3	+37.08
57	Golden Lad of Glenwood Farm	3	+35.08
58	Tormentor Summit Lad	4	+34.39
59	Melia Ann's Hero 4th	3	+33.50
60	Keepsake's Golden Lad	5	+32.18
61	Bessie Bate's Lad	2	+30.80
62	Nutley Tones Owl	3	+30.55
63	Flying Fox's Oxford Duke 2d	2	+29.30
64	Lady Letty 4th's Rioter	2	+28.33
65	Golden Lad of Summit	6	+27.79
66	Golden Alcazar	3	+27.32
67	Foxhall's Jubilee	10	+26.64
68	Eminent's Pilot	3	+24.18
69	The Owl of Meridale	5	+24.17
70	G. G. Chief of Ashburn	3	+23.75
71	Imp. Rozel's Noble	2	+22.76

TABLE 1—(*Continued*)

NO.	NAME OF BULLS	NO. OF PAIRS	NET CHANGE LBS.
72	Eminent 4th	5	+21.54
73	Interested Prince	21	+21.07
74	Pogis 75th of Hood Farm	7	+21.00
75	Sayda's Heir 3d	15	+20.87
76	Eminent of Acca Farm	3	+20.39
77	St. Oner's Torono	2	+20.32
78	Flying Fox's Victor	2	+18.58
79	St. Lambert's Ridgewood King	2	+16.32
80	Loretta's King	18	+15.94
81	Romulus of Spring Hill	4	+13.34
82	Cream Princess' Fritz	2	+12.57
83	Irene's King Pogis	16	+12.31
84	Anderson's King	2	+11.11
85	Storrs Golden Lad	2	+9.80
86	The Warden	12	+8.47
87	Lord Letta of Merridale	2	+7.89
88	Eva's Grey Fox	2	+7.67
89	Oonan's Count	8	+7.55
90	Valentines Oonan	10	+5.19
91	Marigold St. Helier	4	+4.42
92	Noble of Oaklands	3	+4.24
93	Fairfield's Chancellor	2	+3.51
94	Exile of the Highlands	4	+3.23
95	Foxy's Brown Poet	7	+2.54
96	Nimbus of Brondale	3	+1.59
97	Gedney Farm Oxford Lad	2	+1.57
98	Foxy's Fox of Althea	2	+1.52
99	Golden Butter Lad	2	+1.25
100	Pedro's Vidi	2	—0.51
101	Mabel's Raleigh	3	—1.46
102	Merry Maiden's Grand son	6	—3.27
103	Model's Oxford Lad	5	—6.99
104	Lookout Torono	17	—7.94
105	Hood Farm Golden Lad 4th	3	—8.37
106	Hazel Fern Golden Kin	8	—8.74
107	Eurybia's Son	3	—9.94
108	Rosetta's Golden Lad	5	—10.04
109	Pogis of Goliad	3	—12.48
110	White Oak Monarch	3	—12.64
111	Prince Noel	4	—13.04
112	Mr. Inez Marigold Pedro	3	—13.49
113	Tonona Pogis	14	—14.00
114	Fontaine's Caiest	5	—15.01
115	Imp. Noble Fontaine Raleigh	5	—15.04
116	Lady Letty's Victor	15	—15.70
117	Guenon's Lad 2d	2	—15.80
118	Oxford's Brigadier	2	—17.48
119	Cinxia's Gamboge Lad	3	—17.69
120	Portland Prospect	3	—18.98
121	Gamboge's Knight	5	—20.07
122	Oxford Daisy's Flying Fox	6	—20.38
123	Hood Farm Torono 21st	4	—20.85
124	Copper Baron	2	—21.24
125	Karnak's Noble	4	—21.25
126	Jersey Lad's Caspar	5	—21.69
127	Marigold's Exile King	8	—22.37
128	Nero's Garfield Lad	2	—22.72
129	Alcarano	4	—23.69
130	Oonan's Major	2	—25.33
131	Merry Miss' Son	5	—26.17
132	Meridale Interested Prince	6	—26.55
133	Oonan's Conqueror	2	—27.48
134	Fontaine's Lodestar	4	—27.56
135	Seven Gates	5	—29.25
136	Noble's Jolly Golden Lad	2	—29.78
137	Naiad's Golden Lad	3	—31.57
138	Romeo of Sheomet	4	—31.75
139	Willson's Exile	2	—33.00
140	Lad's Oxfordshire	2	—33.39
141	Mabel's Poet	5	—36.33
142	Eminent's Raleigh	2	—37.30
143	Reservation Stoke Pogis	5	—37.98
144	Fairy Glen's Raleigh	5	—38.32
145	Gertrude's Jap	2	—38.47
146	Rosaire's Olga Lad	13	—38.93
147	Pogis 95th of Hood Farm	5	—39.71
148	Prince Ramaposa	2	—39.83

TABLE I—(*Continued*)

NO.	NAME OF BULLS	NO. OF PAIRS	NET CHANGE LBS.
149	Valentine's Count	6	—40.75
150	Sultana's Oxford Lad	3	—40.77
151	Melia Ann's Berkshire	2	—42.39
152	Glory's Pedro	2	—42.85
153	Oxford King of Fernwood	3	—44.37
154	Gertie's Son's Jamont	2	—45.00
155	Pogis Alden Boy	2	—45.04
156	King Allie Rioter	2	—45.11
157	Hood Farm Torono 20th	19	—45.59
158	Olga Hazel Pogis	2	—46.97
159	Marigold's Champion	3	—47.12
160	Sensational Fern	3	—47.58
161	Imp. King of Hambie	2	—48.02
162	Rosaire's Lad of Glenwood	2	—48.79
163	Owl's Model Fox	2	—49.41
164	Rochette's Noble	2	—49.84
165	Biltmore's Torment	4	—50.61
166	Gendey Farm Girl's Oxford	14	—53.27
167	Mistletoe Pogis	2	—53.30
168	Altama's Pogis	3	—53.31
169	Raleigh's Fairy Boy	10	—53.67
170	Quintin Owl	3	—56.07
171	Altama Interst	4	—59.39
172	Golden Lucy's Eminent Lad	7	—60.09
173	Eminent 10th	9	—60.15
174	The Imported Jap	11	—61.91
175	Gamboge's Oxford Lad	2	—64.25
176	Roving Gipsy	2	—64.75
177	Golden Laddie of C.	3	—65.75
178	Lord North	2	—65.98
179	Inez's Stoke Pogis	4	—66.65
180	Golden Paul	3	—68.05
181	Oxford John D.	3	—68.26
182	Ben Hur Pogis	2	—68.79
183	Island Lodestar	6	—70.89
184	Daisy's Prince of St. L.	2	—73.38
185	Pogis 94th of Hood Farm	2	—75.91
186	Amy's Chief	4	—76.37
187	Fontaine's Duke	6	—76.54
188	St. Mawes	2	—78.44
189	Fontaine's Count	2	—80.51
190	Pedro of Brick House Farm	3	—82.31
191	Jacoba's Emanon	9	—84.27
192	Fad	2	—85.61
193	Cowslip's Ashley	3	—87.42
194	Benedictine King	2	—88.14
195	H. F. Golden Fern's Lad	7	—90.49
196	Tormentor's Torono	5	—90.51
197	Girldine's Champion Pogis	3	—90.60
198	Kings Rioter Lawrence	2	—94.96
199	Gazelle's Fawn Rioter King	3	—98.85
200	Noble Peer	4	—98.85
201	Violet's Oakland Count	2	—99.71
202	Minaret Exile	9	—100.59
203	Brown Lassie's Compass	5	—100.61
204	Fort Hill Farm Torono	2	—102.25
205	Viola's Golden Jolly	2	—102.51
206	Oaklands Sultan King	2	—103.95
207	Gertie's Son's Boy	2	—106.18
208	Adelaide's Merry Pogis	3	—108.14
209	Mona Rose's Glory	5	—110.94
210	Financial Raleigh	4	—115.05
211	Jacoba's Premier	3	—115.10
212	Magery Golden's Fox	4	—119.76
213	Fern's Air	2	—123.55
214	Harry B. Gordon	2	—124.46
215	Combination Golden Lad	3	—138.06
216	Hector Marigold	2	—144.12
217	Lady Mary's Fox	2	—148.02
218	Rosaire's Golden Lad	2	—149.95
219	St. Helier of Sheomet	3	—150.59
220	Oonan 23d's Grandson	3	—156.92
221	Jubilee of Bois d'Arc	3	—162.92
222	Oxford Lad's Owl	2	—164.84
223	Hood Farm S. Tormentor	3	—219.72
224	Gertie's Son of Washington	3	—227.01

This table gives to the breeder information of a sort he has never had before. It enables him at once to form a real judgment of the worth of various bulls which appear in the pedigree of Jersey cattle. Many of the bulls in the minus side of the table have at different times been regarded as leaders of the breed and they and their progeny have sold for fabulous prices. With a scientific measure in hand of their actual effect upon the breed it will in the future be exceedingly difficult to persuade any intelligent breeder of the transcendent merits of these minus sires. On the theoretical side there are many interesting points which flow from this and similar tables, but space cannot be taken here for their discussion.

After presenting the basic tables for milk production, fat percentage, and net fat, similar to table 1 here, the complete paper goes on to discuss various related problems, such as the relation of inbreeding, amount of Island bred stock, etc., to production. The chief results of the whole study may be stated as follows:

1. There are 224 Jersey Registry of Merit sires which meet the requirements of this performance test for their transmitting qualities in milk production. One hundred and five of these sires or less than one-half raise the milk production of their daughters over that of the dams of these daughters. The largest number of daughter-dam pairs is 39 for the sire Hood Farm Pogis 9th, 55552. Of those sires which have a large number of pairs, Hood Farm Torono 60326 with 34 pairs stands first in his transmitting qualities raising the milk production of his daughters on the average 2620.1 pounds.

2. Two hundred and twenty-five sires are included in the table giving the sires which met the requirements of the daughter-dam performance test for transmitting qualities of butter-fat percentage. Out of this number 101 sires raised the butter-fat percentage of their daughters' milk as compared with the butter-fat percentage of the dams of these daughters. The leading sire in this butter-fat percentage performance test was Clear Brook Chief 74685 raising his daughters on the average 1.338% of butter-fat. This sire had two daughter-dam pairs. Hood Farm Pogis 9th leads in number of daughter-dam pairs with 42. This bull raised the butter-fat percentage of his daughter on the average of 0.243% over the butter-fat percentage of the dams of their daughters.

3. The sires mentioned as superior in the milk transmitting ability, Hood Farm Torono and Spermfield Owl, do not check up so well in their ability to transmit high butter-fat percentage. Hood Farm Torono caused his daughter on the average to be 0.225 per cent of butter-fat below what the dams of these daughters produced. Spermfield Owl only raised his daughters on the average 0.027% of butter-fat over what the dams of these daughters produced.

4. There are 224 sires of known transmitting ability for net butter-fat. Of this number only 99 sires raise the butter-fat production of their

daughters over that of their dams. The sires which raised the production of their daughters' butter-fat most were Sans Aloi 81012, Signal's Successor 72758, and Golden Glow's Chief 61460. The sires which made the deepest impress on the breed by raising the butter-fat of the largest number of daughters over that of their dams was Hood Farm Torono with 34 pairs and an average increase for each daughter of 121.51 pounds of butter-fat. The next bull, Spermfield Owl, with 26 pairs raised the butter-fat production 97.71 pounds on the average for each of his daughters. Some of the bulls lowering the production of their daughters markedly were Gertie's Son of Washington 83799, Hood Farm S. Tormentor 96311, and Oxford Lad's Owl 75599.

5. The information summarized above was arranged to reveal the transmitting qualities for milk production, butter-fat percentage and butter-fat of Jersey sires to their sons. There were 159 sires which had sons whose progeny performance was known. Of this number 69 or significantly less than half had sons who raised the butter-fat production of their daughters over that of their dams.

6. The sires of superior merit are defined as those which raise the milk production and butter-fat percentage of their daughters as compared with that of their dams. The inferior sires are defined as those sires who lower the milk production and butter-fat percentage of their daughters as compared with the same variables in their dams. The superior sires so defined were arranged by the amount of butter-fat that they increase the production of their daughters over that of their dams. The inferior sires were classified according to the amount of butter-fat that they decrease the production of their daughters in comparison with that of their dams. These two groups of sires are subjected to four generation pedigree analysis to determine their inbreeding and relationship, the amount of Island and American stock, "males and females" and "on the sire's side of the pedigree and on the dam's side of the pedigree," and the individual animals most frequently repeated into two groups of pedigrees.

7. There are 28 sires in the group of sires superior in their transmitting qualities for milk production and butter-fat percentage. In the group of sires inferior in their transmitting ability for these two characters there are 47 sires, a ratio of 1 to 1.7. Such a difference speaks for itself. It emphasizes with startling clearness the need of exact knowledge of the transmitting qualities of bulls to be bred as sires and of the necessity for exact knowledge of the inheritance of milk production and butter-fat percentage.

8. The inbreeding coefficients show that the sires of superior merit have 7.08 % of the greatest possible inbreeding up to the fifth generation. The inferior sires are inbred 9.65% of the greatest possible amount (continued brother and sister mating). The group of sires poorer in their transmitting

qualities are consequently more inbred than the group of sires with superior transmitting qualities.

9. The analysis of the pedigrees for the amount of relationship that may exist between the sire and dam of the individual bulls in the superior group and in the inferior group shows that there is little or no difference in the amount of this relationship within the two groups.

10. The resolution of the four generation pedigrees into the Island bred Jerseys and by difference into the American bred Jerseys showed the mean number of Island males in the pedigrees of the superior sires' group to be 8.07 and the mean number of females 7.79. The mean number of Island bred males in the inferior sires' group were shown to be 6.94 and the mean number of females 6.55. The group of sires which increased the production of their daughters over that of their dams had, consequently, more Island bred stock in their pedigrees. The females in each group of the pedigrees had a smaller proportion of Island bred individuals than the males had in each of the groups.

11. Study of the pedigrees of these two groups of sires discloses the fact that all the animals which appeared in the pedigrees of the superior sire on the male side of the pedigrees more than four times or on the female side of the pedigree more than three times also had appearances in the pedigrees of the sires inferior in their transmitting qualities. This fact alone makes it clear that the appearance of certain famous animals in pedigree of a given bull is no guarantee of that particular bull's worth.

My former student and successor at the Maine Experiment Station, Dr. John W. Gowen, expects presently to publish similar investigations for the other chief dairy breeds. It is a great pleasure to acknowledge the faithful and painstaking help of my two assistants, Mr. John Rice Miner and Dr. John W. Gowen in bringing this investigation of the Jersey breed to completion. Without their aid it is doubtful if this would ever have been finished, particularly in view of the influences, which have operated on my own scientific work during the past three years.

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[3] The complete paper will have the following bibliographic status: Pearl, R., Gowen, J. W., and Miner, J. R. Studies in Milk Secretion, VII. Transmitting Qualities of Jersey Sires for Milk Yield, Butter-fat Percentage and Butter Fat, *Maine Agr. Expt. Stat. Ann. Rept. for* 1919, pp. 89–204.

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